The distances between the junctions were BM = 2·57 cm. and MT = 2·6 cm. Hence by the formula of § 2,

$$\frac{k(\text{M, B})}{k(\text{T, M})} = \frac{73{\cdot}1 \div 2{\cdot}6}{79{\cdot}0 \div 2{\cdot}57} = \frac{28{\cdot}1}{30{\cdot}7} = 0{\cdot}91.$$

Aberdeen granite:

$$v(\text{T}) = 81^{\circ}{\cdot}1.$$

$$v(\text{M}) = 145^{\circ}{\cdot}6.$$

$$v(\text{B}) = 214^{\circ}{\cdot}6.$$

The distances between the junctions were BM = 1·9 cm. and MT = 2·0 cm.

$$\frac{k(\text{MB})}{k(\text{TM})} = \frac{64{\cdot}5 \div 2{\cdot}0}{69{\cdot}0 \div 1{\cdot}9} = \frac{32{\cdot}2}{36{\cdot}3} = 0{\cdot}88.$$

§ 13. Thus we see, that for slate, with lines of flux parallel to cleavage planes, the mean conductivity in the range from 123° C. to 202° C. is 91 per cent. of the mean conductivity in the range from 50° C. to 123° C., and for granite, the mean conductivity in the range from 145° C. to 214° C. is 88 per cent. of the mean conductivity in the range from 81° C. to 145° C. The general plan of apparatus, described above, which we have used only for comparing the conductivities at different temperatures, will, we believe, be found readily applicable to the determination of conductivities in absolute measure.

II. "The Kinematics of Machines." By T. A. HEARSON, M.Inst.C.E., Professor of Mechanism and Hydraulic Engineering, Royal Indian Engineering College, Coopers Hill. Communicated by Professor COTTERILL, F.R.S. Received March 19, 1895.

(Abstract.)

In this paper the author regards a machine as an embodiment of a movement. The method of construction and the proportions of the parts are not taken into consideration, except so far as may be necessary to explain the conditions requisite for the kinds of motions with which they are supposed to be endowed. All other considerations relating to form and proportion are omitted, as belonging to the subject of machine design. Neither does the author take account of the forces which actuate and oppose the movement of the machine, such matters belonging to the subject Dynamics of Machines.

The object of the paper is to analyse the movements only, and to

show the likeness and the differences between machines in similarities in the movements or the contrary.

It is claimed by the author that in those movements the principal feature of a machine resides, distinguishing it from other engineering constructions.

It is shown that all movements, however complex, are derived from the association together of some of a comparatively limited number of kinds of more or less simple motions, which take place between consecutive directly connected pieces.

Certain geometrical laws are enunciated, from which are derived the conditions necessary for the association of those motions together in one machine. It is shown that those laws preclude the existence of certain combinations of motions, and it is suggested that one may be enabled by this analysis to enumerate an exhaustive list of the possible combinations which must include all existing machines, and suggest the design of others not in existence. Moreover, by attaching to each kind of motion a suggestive symbol, a method of expressing the constitution of a machine movement by a simple formula is proposed, whereby similarities and differences between machines may be exhibited at a glance.

The author commences by considering a very simple mechanism, consisting of four bars united in one continuous linkage by four pins which have parallel axes. By imagining the length of the links to undergo variation from zero to infinity, it is shown that this simple mechanism is representive of all the simple plane mechanisms, and, by imagining other variations to occur, this same mechanism is shown to be representive of still further classes of mechanisms, in which the parts do not move in or parallel to one plane. In this simple mechanism the relative motions of consecutive pieces are either turning, when one piece revolves completely around relatively to the other, the representative symbol being the letter O, or swinging when one piece turns through a limited angle relatively to the adjoining one, represented by the letter U.

The first law enunciated, which governs the association of the O and U motions, is founded on the geometrical fact that the sum of the three angles of a plane triangle is constant, and the sum of the four angles of the quadrilateral therefore also constant. After a complete revolution the angle between the bars is considered to have been increased or diminished by 2π. With this extension of the proposition the constancy of the sum of the angles is unimpaired.

From this it is seen to be impossible for only one motion to be turning and the other three swinging, otherwise the sum of the four angles would increase or decrease by 2π each revolution.

The second law, which governs the association of the motions, has to do with the proportions between the length of the links necessary

to permit of complete turning. This is founded on the fact that one side of a triangle cannot be greater than the sum of the other two. From these two laws together it is shown that it is impossible to have two O's alternating with two U's.

Next it is pointed out how the U motion may be provided for by constructing a circular slotway in one piece, and shaping the other piece to fit the slotway, so that by imagining the radius of curvature of the slotway to be indefinitely increased a relative movement of reciprocating sliding motion, represented by the symbolical letter I, will be substituted for the swinging motion U. A slide being conceived to be a swing through a zero angle about an infinitely distant centre, the previously mentioned laws will apply to associations containing I motions, and it will follow that a combination of three slides and one swing is precluded by the first law.

If four slides are associated, in which all four of the links of the original mechanism are to be conceived to be infinitely long, an indeterminate motion will result comparable to the motion which would be possible if five bars were joined by pairs in a closed circuit. One of the slides may be suppressed, and a definite motion will result from three slides.

If the foregoing analysis be compared with that due to Reuleaux, to which it bears a close resemblance, it will be seen that Reuleaux conceives that the elementary essential components of machines are the *pairs* of consecutive links which are in mutual contact, whereas it is here proposed that the relative *motions* of consecutive links should be regarded as the essential elements or components of a machine movement. Whilst the pairs of surfaces of contact of consecutive pieces should be formed to suit the kind of relative motion which those pieces are required to undergo, yet the forms of those surfaces do not themselves entirely govern the character of the motion.

Reuleaux assumes that what he calls a turning motion and the I motion are entirely governed by the forms of the surfaces of mutual contact, but shows that to ensure a more complex motion a restraint is required to be imposed by means external to the two links. Those additional means of constraint have to be included with that due to the forms of the surfaces of mutual contact in the conception of a complete pair, and often the whole mechanism is required to complete one pair contained in it.

Reuleaux does not attempt to discriminate between a turning and a swinging pair; the same pair of surfaces of mutual contact is suitable for both; the difference consists of a difference only in the rest of the mechanism, yet the difference in the two motions is most apparent, and is very important, both kinematically and also from the practical engineer's point of view.

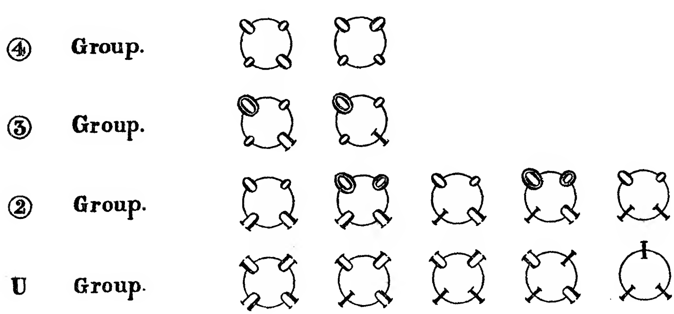
No advantage is derived from analysing a machine into parts such as pairs if it requires the whole machine to complete one of the parts.

The enunciation and the explanation of the influence of the first law previously mentioned, of the constancy of the sum of the four angles of a quadrilateral in governing the association of the OU and I motions in one mechanism, is one of the important original features of this paper.

The influence of the second law, viz., that the two sides of a triangle are together not less than the third, in limiting the association of the O, U, I motions, is now also for the first time pointed out, though Reuleaux and others have, without formally enunciating the law, made use of the fact to determine the proportions necessary for certain suggested movements.

By the application of these governing laws one is able to write an exhaustive list of all the possible combinations in one simple mechanism of the three simple O, U, I motions, and to explain why other combinations are precluded.

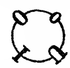
Fourteen distinct combinations are possible, and only fourteen. They are exhibited by the following formulæ, in which a large O associated with a small o signifies that in one case adjacent links turn relatively to one another so as to continuously increase the angle between them, and in the other to continuously diminish the angle. The double ◎ signifies that two complete revolutions accompany one complete to and fro swing or slide.



Following Reuleaux, the author applies the principle of the "inversion of the kinematic chain," considering it to be a continuous sequence of links in a closed circuit containing a sequence of elementary motions. In explaining what is meant by inversion, it is pointed out that relatively to an observer or user of a machine one piece is fixed. This is called the frame of the machine. Each one of the four links may in turn be made the fixed or frame link, and

although the relative motion of the four links will in all cases remain unaltered, the absolute movement, or movement relatively to the user of the machine, will in general be different for each fixing, and constitute a new machine movement. Changing the fixed or frame link is called the "inversion of the chain."

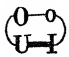
The author makes use of the term "primary pieces," originally suggested by Rankine for those links which are in sequence with and directly connected to the frame link, and shows that if, after inversion, the new primary pieces have the same kind of motions as the previous primary pieces had, the consequent machine movement is not a new one, but a repetition of a previous one.

From the mechanisms  **and**  only can four different machine movements be obtained by inversion. From the others 3, 2, or only 1 can be derived.

They are distinguished from one another in the formula by using a thick line for the frame link. Thus

 signifies a machine movement like that employed in the crank and connecting-rod engine.

 is exemplified in the oscillating engine much used in paddle-wheel steamers.

 is found in Stannah's pendulum pump, and

 is the movement adopted by Rigg in the design of his high speed engine. The intimacy of the relation of this engine to the preceding ones is here for the first time indicated.

In all, thirty-two and only thirty-two distinct machine movements can be derived from the fourteen previously enumerated mechanisms by inversion.

It is shown that Reuleaux's principle of inversion can be applied with more advantage and consistency if a machine movement is analysed into its component motions than if a machine is analysed into its component pairs, and the notation lends itself to a very clear exhibition of the effect of inversion.

The author next discusses the relation of cams and spur-wheel mechanisms to the foregoing kinematic chains, showing that they are the result of the suppression of one of the previous four links and the amalgamation of the two adjoining simple motions into one more complex. A comparison is also made with belt gearing and expressive formulæ suggested.

The author then passes to the consideration of machines the parts of which do not move parallel to one plane.

Reuleaux was the first to show that if the links of the previously mentioned kinematic chains be bent to the form of great circles of a sphere the axes of the connecting pins will be radial, and the previously mentioned machine movements will be possible under the modified circumstances.

In spherical motion the counterpart of what is a slide in plane motion could be obtained by a swinging motion about a pole of which the bent link is the equator. The motion is to be conceived as due to the use of two bent links, the length of one of which is a quadrant of a great circle of the sphere.

In these so-called spherical mechanisms, Law I has to be modified as follows:—

The sum of the four angles of the spherical quadrilateral varies, having a value of 3π for a maximum and 2π for a minimum.

This and Law II, which is the same as before, will preclude the same combinations in spherical mechanisms which were precluded in plane mechanisms.

Law I explains at once why in Hooke's joint, which is the spherical counterpart of Oldham's coupling, the angular velocity-ratio of the connected shafts is not constant, whereas in Oldham's coupling it is.

The author points out that the kinematic chain containing three slides cannot be adapted to give a movement on a sphere. The virtual construction would consist of a spherical triangle between the links of which no relative motion is possible, and there is not room on the sphere for a movement at each joint of a bent quadrilateral, the length of each side of which is equal to a quadrant. But a three-slide mechanism can be adapted to give motion on the surface of a cylinder, and it is the only one of the fourteen kinematic chains which can be so adapted, and examples of it are found in the various helical motions so largely used. (The letter V is used to represent helical motions.) This method of showing the relation between screw motions and plane motions is a novel feature of the paper.

The remaining mechanisms consist of those in which the axes of the turning and swinging motions neither meet nor are parallel. They include the motion which occurs at a ball-and-socket joint represented by $\ominus$. The method of classification according to the proposed scheme is summarised as follows:—

All simple machine movements may be ranged in four divisions, viz.:—

1. Consisting of plane mechanisms, in which the pieces move in or parallel to the surface of a plane.

2. Spherical mechanisms, in which the pieces move in or parallel to the surface of a sphere.

3. Cylindrical mechanisms, in which the pieces move in or parallel to the surface of a cylinder.

4. The remainder, to which the name conoidal mechanisms is given, in which the axes of the swinging and turning motions neither meet nor are parallel.

The mechanisms in each of these divisions are classed in two sub-divisions.

Sub-division S, with surface contact of consecutive links.
Sub-division P, with point contact of consecutive links.

The mechanisms of sub-division S of divisions 1 and 2, 1_s and 2_s will consist of those in which O U I motions only are used.

Those of 3_s will include the helical or V motion, and

Those of 4_s will include the motion $\ominus$ requiring the use of a ball-and-socket joint.

To the pairs of links which have the relative motions O, U, I, V, Reuleaux has given the name lower pairs. Reuleaux claimed two characteristics for lower pairs, viz. :—

1. Definiteness of motion derived from the surfaces of mutual contact themselves.

2. The possibility of distributing the contact over an area which may be extended as much as desired.

If it is desired to differentiate between the O and U motions, Reuleaux's turning pair cannot possess the first characteristic.

The second characteristic is of considerable value in relation to the liability to abrasion and wear, but the advantage of greater immunity against wear has to be purchased at the cost of a more complicated construction and a more restricted character of movement.

As examples—

The mechanism consisting of a pair of spur wheels turning in bearings which are at a fixed distance apart will belong to 1_p.

A pair of bevel wheels will belong to 2_p.

The so-called cylindrical cam motion will belong to 3_p, and the worm-and-worm wheel mechanism to 4_p.

The mechanisms in each of the eight sub-divisions are still further sub-divided into combinations. The combinations of 1_s, 2_s, and 3_s, are exhaustively enumerated, and it is suggested that an extension of the methods of applying the geometrical laws would lead to the preparation of an exhaustive list of the possible combinations in the other sub-divisions. The combinations are still further sub-divided into inversions according to Reuleaux's principle of the inversion of a machine.

Further than this there will be varieties of any inversion differing in the details of the construction and uses of the machine movement.

Lastly, the author proceeds to show how the foregoing considerations assist in the analysis of compound mechanisms. It is assumed

that practically all compound mechanisms contain a continuous mechanism A, of not more than four links, from which definiteness of relative motion of all the other links is derived. Any two links of A in their exact length, or longer or shorter, may be adapted to form with two new links a second mechanism B, and any two of A or B, or one of A and one of B, may be adapted to form with two still further added links a third mechanism C, and so on. In this way a definiteness of relative motion of many links in a compound mechanism is derived. The notation lends itself to a clear exhibition of the manner in which two or more simple mechanisms are associated together, and the compound mechanism built up.

III. "On the Effect of Pressure of the Surrounding Gas on the Temperature of the Crater of an Electric Arc Light. Preliminary Notes of Observations made at Daramona, Streete, co. Westmeath." By W. E. WILSON. Communicated by Professor FITZGERALD, F.R.S. Received April 25, 1895.

Of late years it has often been assumed that the temperature of the crater forming the positive pole of the electric arc is that of the boiling of carbon. The most modern determinations give this point as about 3300°—3500° C.

Solar physicists have thought that the photosphere of the sun consists of a layer of clouds formed of particles of solid carbon. As the temperature of these clouds is certainly not below 8000° C., it seems very difficult to explain how carbon can be boiling in the arc at 3500° and yet remain in the solid form in the sun at 8000°. Pressure in the solar atmosphere seemed to be the most likely cause of this, and yet, from other physical reasons, this seemed not probable.

In order to investigate whether increased pressure in the gas surrounding an electric arc would raise the temperature of the crater, I had an apparatus made by the Cambridge Instrument Company. It consists of a strong cast-iron box, which was tested by hydraulic pressure to 2000 lbs. per square inch. In the following plan, A is the box, B and C are the two carbon poles enclosed in steel tubes. The negative carbon was kept in position against a copper ring by a spiral spring behind it. The positive carbon was hand fed by a friction roller, which was moved by a handle F outside the box. A steel tube H was screwed into the box at such an angle that, by looking down it, we could see well into the crater of the positive pole. The end of this tube is closed by a glass lens, which formed an image of the crater at a distance of 80 cm.